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Investigating Human/System Interfaces and Interactions in a ìLights-Outî Operational Environment

Walt Truszkowski
Code 588
NASA-Goddard Space Flight Center
Greenbelt, MD 20771 U.S.A.
e-mail: Walt.Truskowski@gsfc.nasa.gov

Elizabeth D. Murphy and Kent L. Norman
University of Maryland, Department of Psychology
College Park, MD 20742 U.S.A.
e-mail: bmurphy@smtplink.cta.com;
kent_norman@mail.lap.umd.edu

Abstract

Previous researchers have assumed that an analyst or engineer, who has not been maintaining an active awareness of an automated system's behavior or context, will be able to respond to a call when his help is needed to address a problem that the system itself cannot handle. As an example, in planning for lights-out spacecraft operations, provision has been made for notifying an appropriate human operator or analyst to respond to a spacecraft anomaly that cannot be handled directly by the lights-out ground system. Although it is recognized that notifications will occur infrequently, little provision has been made to compensate for the normal human forgetting that is likely to occur between human involvement with the system. Studies being conducted at the NASA-Goddard Space Flight Center are investigating ways to address this issue and bring the human expert back "into the loop" as quickly and effectively as possible.

Key Words: lights-out operations, agents, human-computer interactions, cognitive studies

Issues driving the Research

There are two hypotheses that are driving the current research into the cognitive aspects of human interaction and interfacing with highly automated systems. These are :
1. proper data/.information visualization can compensate for a user not maintaining a awareness of the operational context of a system; and
2. proper data/information visualizations can compensate for the levels of abstraction involved in presenting system dynamic behaviors .

Let us briefly consider these two hypotheses.

Compensation for Lack of Operational Context

As implied in the Abstract, lack of human interaction with an automated system over time can result in the human's loss of knowledge about the functioning of a system or what the system is supporting.   However, the need to reduce the operational costs of systems and the need to bring more objectivity into system operations requires developing highly automated systems. Reconciling these needs with the propensity of humans to forget with inactivity leads us to consider the types of data and information visualization techniques that can be used to readily bring a human up to speed when it is determined by the automated system that outside help is required to solve a system problem.

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The Figure 1 graphically illustrates the situation in which the problem of lack of maintaining an operational context arises.

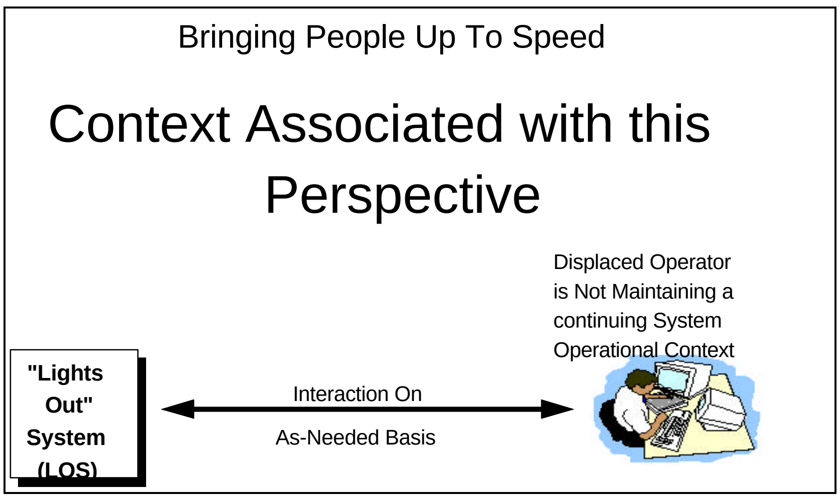

Figure 1.

Levels of Abstraction

In dealing with the concepts of levels of abstraction two major aspects arise. One deals with the fact that user interactions and interfaces with intelligent autonomous systems are not fixed. The second deals with the fact that what a user “sees” is sometimes far removed from the reality that is being controlled.

The lights-out system depicted in Figure 1 is envisioned to be an intelligent system capable of learning from past experiences And adapting to new situations. This level of autonomy has some very interesting implications for human-system interactions considerations. Figure 2 illustrates one of these.

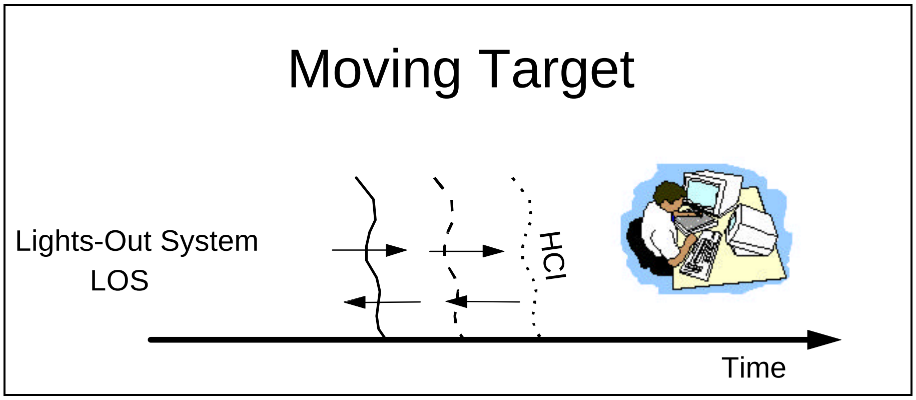

Figure 2

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The boundary between a LOS and a human operator (it's associated HCI) is a moving target if the LOS is "intelligent" and capable of adaptation through learning. The same is true in the opposite direction.

The issue of levels of system abstraction is a very interesting one. As an illustration let us consider a somewhat simplified view of a space/ground satellite system. The "reality" in this system is the spacecraft itself. However, through the mechanisms of selected telemetry and the sequence of models that the telemetry and additional processing of it bring into existence the more opportunity there is for deviating from the reality to some abstract notion of it.

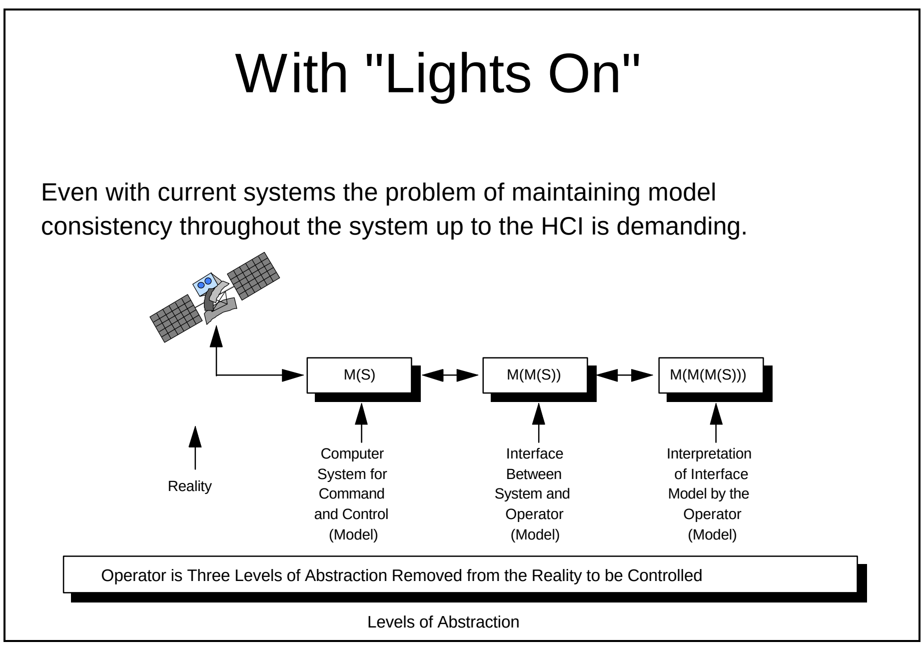

Figure 3

Compensating for these levels of abstraction requires, in our opinion, sophisticated data and information visualization techniques. When we consider this issue of abstraction in the context of lights-out operations we see that lights-out operations may not directly contribute to an increase in the number of levels of abstraction. However, lights-out operations does introduce a temporal discontinuity that needs to be dealt with.

All of the discussion so far has been in the context of lights-out operations. In the next section we briefly introduce an experimental proof-of-concept lights-out system, elements of which will support the cognitive studies of human interaction and interfacing with highly-automated systems.

Lights-Out Ground Operations System (LOGOS)

In todayís spacecraft ground control stations, human operators typically perform command-and-control functions, including monitoring spacecraft status and uplink of commands to the spacecraft, as well as fault detection, isolation, and correction. This full-staffing approach to low-Earth-orbiting mission operations can be extremely labor intensive. In a series of initiatives to reduce costs, NASAís Goddard Space Flight Center is developing a set of concepts to support ìlights-outî operations, which include fully autonomous ground

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operations. These initiatives make use of technologies which have emerged only relatively recently, especially agent technology supporting the concept of “surrogate operators”.
These concepts are being tested in the Lights-Out Ground Operations System (LOGOS), an experimental testbed at NASA-Goddard.

LOGOS has two major goals. These are: 1. to establish an environment that supports the development, deployment, and evaluation of evolving agent-based software concepts in the context of lights-out operations; and 2. to support evaluation of data/information visualization concepts and cognitive studies. Additionally LOGOS demonstrates how agents as “tool users” can be integrated into an agent community responsible for running a ground system.

LOGOS Overview.

As a prelude to considering the LOGOS concept let us first consider the idea of an agent as a surrogate controller.

Figure 4. illustrates that in a lights-out system environment there will be several layers of automation. Agent technology will be required to provide the higher-levels of automation required to compensate for the lack of human presence in the lights-out environment.

Figure 5. illustrates the current concept for LOGOS.

The agent community of LOGOS attempts to handle any spacecraft anomaly which arises. In the event that it cannot, it establishes an interaction with a remote analyst for help. In

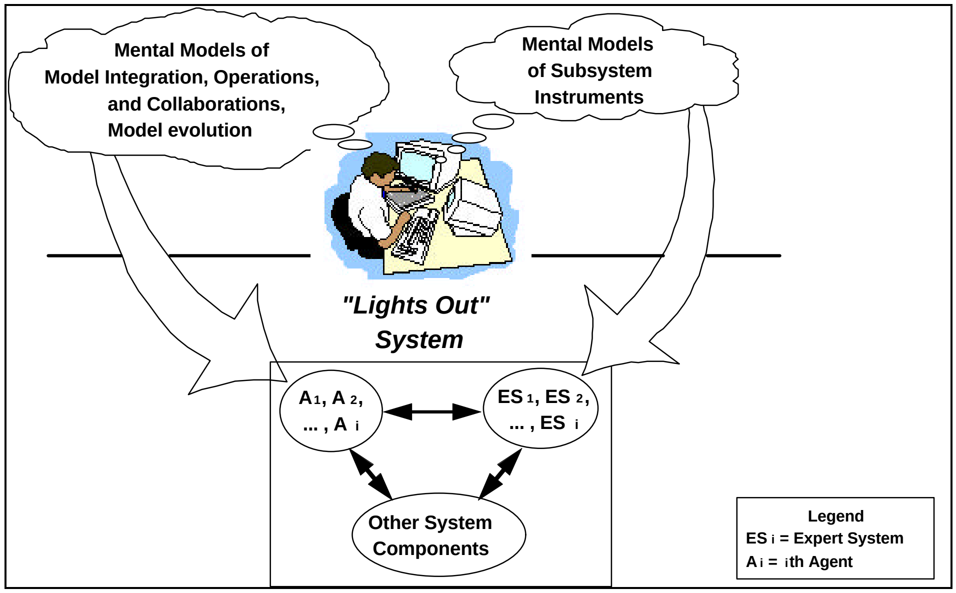

Figure 4. Roles of an Agent as Surrogate Controller

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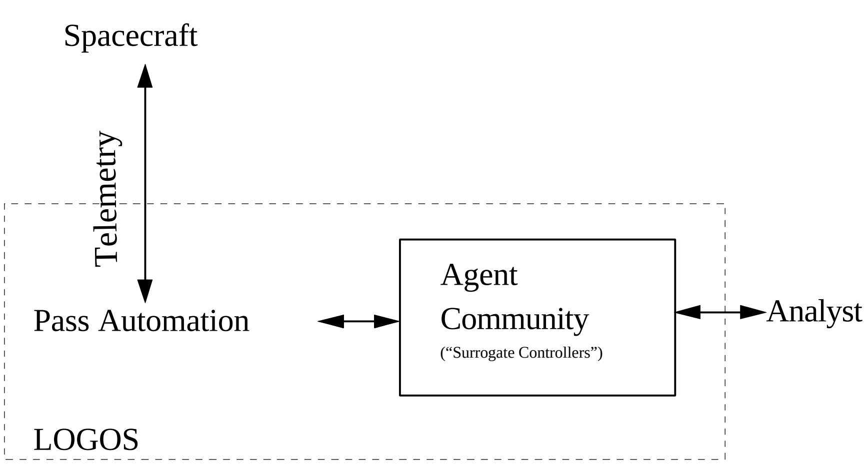

Figure 5. The LOGOS Concept

doing so it needs to provide to the analyst sufficient contextual information and appropriate representations of what it considers to be the anomaly in order to enable him/her to successfully address the problem.

LOGOS provides an infrastructure for the investigation of cognitive issues that bear on human performance in a lights-out environment.

Major Cognitive Issues in Autonomous Spacecraft Operations

It may seem like a contradiction in terms to raise a concern for demands on human cognitive capabilities in the context of autonomous systems: If a system operates autonomously, then no humans are involved, by definition. At times, however, human experts will be called upon to deal with unforeseen problems (anomalies) that are outside the scope of autonomous capabilities. At these times, it will be important for system capabilities to support the rapid development of the human analystís situation awareness and for the human to walk a fine line between trust and over-reliance on the automation. These issues directly affect user-interface design decisions, which can be informed by research findings on human performance in highly autonomous systems. Issues of information selection and presentation, for example, are directly linked to the need to foster the analystís trust and rapid internalization of problem situations.

<u>Situation Awareness</u>. When an analyst or team of analysts is paged to deal with an anomalous condition, either on-board the spacecraft or within the automated ground system, the challenge is to provide the information needed, in a usable form, to enable the quick development of situation awareness. Analysts will be experts in their specialties but will be ìout of the loopî with regard to the current situation. Bringing them back into the loop can be considered analogous to bringing an on-call physician up to speed on a patientís condition.

This analogy, the medical model, requires a shift in thinking akin to the shift from supervisory control operations to autonomous operations. Physicians routinely work in the paged mode, consulting with the patientís history and running various tests to ascertain the status of subsystems. Assuming that an adequate context can be provided via visual and, perhaps, audio display technology, it should be possible for the analyst to become

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situationally aware in a short time. The analyst will essentially serve as an expert consultant/troubleshooter, a role different from those of the process operator or the supervisory controller.

<u>Trust versus Over-reliance on Automation</u>. The agent community replaces human operators in monitoring spacecraft operations, detecting anomalies, and resolving anomalies within its capabilities. Over time, analysts will develop some level of trust in the agents, based on their reliability, and it will be tempting to assume that the agentsí diagnosis is always correct. It is unlikely, however, that the agents will be correct 100% of the time, and the human expert will always need to verify their diagnosis. The human needs to have some level of trust yet remain somewhat skeptical.

The issue of trust in automation has been studied in detail in the supervisory-control context, with a study conducted at NASA-Goddard pioneering the investigation of trust in semi-autonomous systems. This study found that, for some analysts, trust in the automation can be fostered by providing information about agent reliability, but others are likely to want some hands-on understanding of agent behavior .[1] The fine line between trust and complacency has received a great deal of research interest, particularly in the aviation domain, where system design has sometimes led pilots down the ìgarden pathî of mode confusion, with over-reliance on automation resulting in air disasters. Display technology can serve to remind analysts of agent roles, status, and levels of reliability. It must also make clear the line of reasoning that resulted in issuing a page to the analyst.

Purpose of the Cognitive Studies

The cognitive studies sponsored by NASA-Goddard (Code 588) are designed to investigate the effects of autonomous spacecraft and ground operations on analystsí situation awareness and trust in automation. The LOGOS environment provides a high-fidelity simulated context for investigating the effectiveness of various visualization techniques, as well as the effects of agent-based software on human performance. In particular, the visualizations available through the Visual Analysis Graphical Environment (VisAGE) offer the opportunity to compare different representations of the same data for their effectiveness in conveying information to the analyst. Results of the cognitive studies will help to establish a context for human problem-solving in a lights-out environment.

Methods of Cognitive Research

The cognitive studies are being conducted in phases tied to the development and maturation of the LOGOS environment and the VisAGE capabilities.

Literature Review. The cognitive studies began with an extensive review of the published literature on such topics as supervisory control, autonomous mission operations, situation awareness, and the effects of automation on human performance. Documentation of anomalies experienced by various missions provided a background for interviews with operational personnel. The review included visualization sites on the World Wide Web. Previous cognitive studies sponsored by NASA-Goddard (Code 588) were reviewed for their findings on 3D visualizations.[2, 3, 4, 5] Further information on the literature review is available.[6]

Interviews. Operational personnel at the Johns Hopkins Applied Physics Laboratory (APL) and at NASA-Goddard participated in open-ended interviews. They described mission operations for a wide range of spacecraft and identified anomalies that required extraordinary levels of human analysis, judgment, and creativity. This activity provided input to development of the LOGOS demonstration scenario that involves a star-tracker anomaly requiring human intervention.

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Usability Studies. At the time of this writing (April, 1998), plans are underway to evaluate the VisAGE visualizations for usability. The current set of visualizations includes 2-dimensional (2-D) and 3-dimensional (3-D) representations generated by test data. For example, the set of visualizations includes both 2D and 3D alphanumeric representations of the data, 2-D and 3-D histograms, 2-D and 3-D strip charts, and a 2-D pie chart.

During the evaluations, operational personnel will interact with the VisAGE tool and respond to items on a questionnaire. Participants will be asked to describe the information they consult in isolating and resolving anomalies in their own operational environments and to answer factual questions based on the visualizations displayed to them. These questions will test the effectiveness of the various visualizations in conveying information to an operator/analyst in a simulated lights-out context. Participants will also be given a set of questions about their attitudes toward automation.

A similar set of evaluations will be conducted on the VisAGE tool with undergraduate students at the University of Marylandís Laboratory for Automation Psychology (LAP). Measures of all participantsí performance will include the accuracy of extracted information and response time. Participants at Goddard will be asked to describe information that was needed but not provided as well as information that was provided but not needed to confirm and resolve an anomaly.

Ideally, it would be desirable to generate the visualizations from actual telemetry data. This capability is under consideration for the future. When telemetry data is available, it will be possible to iterate the usability studies from a more realistic perspective. Similarly, using real telemetry data to drive LOGOS sessions would add a level of realism to usability testing conducted in that environment.

Experimentation. A research environment under development in the LAP simulates some of the LOGOS capabilities. It assumes the existence of an agent community that is capable of monitoring spacecraft operations and of paging a human expert when necessary. In experimental trials to be conducted in the coming months, three independent variables will be manipulated: 1) the level of automated aid provided to the participant, who plays the role of the off-site analyst; 2) the selector of the visual representation(s) viewed by the participant; and 3) agent reliability.

Automated aid will have three levels: 1) one 2-D representation of the data; 2) one 3-D representation of the data; and 3) a 2-D and a 3-D representation of the data. The selector will be the participant (self) or a simulated software agent (automated). Agent reliability will vary between 50% and 75% diagnostic accuracy. Each participant will be assigned at random to an experimental condition. The task will be to confirm or not the existence of the agent-reported anomaly and to assign a level of confidence in each confirmation/non-confirmation decision. Dependent variables will include accuracy in confirming or not confirming the presence of an anomaly, response time, and level of confidence in the decision to confirm or not to confirm.

It is expected that the two-representation condition will support better performance than will either of the one-representation conditions, but only if the 2-D and 3-D displays provide different information. It is expected that results for the dependent measures will correlate significantly with trust in automation and spatial visualization ability (SVA), both of which will be assessed before the experimental trials. SVA will be assessed by a standard test administered on line, and trust will be assessed by questionnaire. It is expected that software agents will facilitate performance when there is high trust in the automation.

Taken together, results of the usability studies and experimental trials will provide feedback to VisAGE and LOGOS developers on the effectiveness of the visualizations and the effects of agent-based software on human performance.

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